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Germination, Survival, and Growth of Lodgepole Pine Under Simulated Precipitation Regimes: A Greenhouse Study

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Amount and distribution of water from 0.0 to 2.0 in/mo affected germination, survival, and growth of lodgepole pine seedlings. Germination increased with increasing amounts of water, but did not appear affected whether water was distributed evenly during the month, or applied once a month. Survival was acceptable when seedlings received 1 in or more of water distributed throughout the month. Overall growth was better at 1.5 or 2.0 in/mo of water.

Keywords: *Pinus contorta*, plant water relations, plant physiology, seed germination.

The climate in which lodgepole pine (*Pinus contorta* Dougl.) grows in the central Rocky Mountains, while warmer and drier than the high spruce-fir zone, is characterized by environmental extremes that can limit regeneration success (Alexander 1974). The amount and distribution of rainfall following snowmelt is a major environmental factor affecting the germination and establishment of lodgepole pine seedlings.

Studies have shown that precipitation early in the growing season is particularly critical to seedling survival, and that up to 90% of the seedling mortality during the first year can be due to drought (Lotan 1964). Indications are that frequent showers of 1 in or more 3 to 4 weeks after germination begins substantially increases lodgepole seedling survival (Lotan 1964, Ronco 1967).

This study was begun to supplement field information on water requirements of lodgepole pine during the first growing season. Seedlings were grown under controlled greenhouse conditions in Fort Collins, Colorado, to measure germination, growth, and initial survival under watering treatments selected to represent the precipitation patterns which can occur following snowmelt in the central Rockies.[2]

Methods and Materials

Seed source.—Lodgepole pine seed used in this study was collected in 1967 at 9,500 ft elevation on the Elk Creek drainage of the Arapaho National Forest near Fraser, Colorado, and stored at 4°C. Germination averaged 67% in 1973.

Soil and seeding.—A fine sand loam of the Darling series, which developed in place from gneiss and schists (Retzer 1962), was collected under a mature spruce-fir stand at 10,500 ft elevation on the Fraser Experimental Forest in central Colorado. Moisture-holding capacities at ⅓ and 15 atmospheres (atm),

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[2]*U.S. Weather Bureau records for a 35-yr period (1931-66) from Fraser, Colorado—approximately 5 air miles from the study areas—at 8,500 ft elevation, indicate that average precipitation from June through October varies from 1.75 in in July to 1.00 in in October with a range of 0.50 to 2.50 in covering most years (U.S. Weather Bureau 1931-66). Monthly precipitation is most likely to fall in either several small storms of 0.25 in or less, or in one or two larger storms.*

determined in the laboratory, were approximately 15% and 31%, respectively. The soil was screened through four-mesh hardware cloth, thoroughly mixed, and placed in pots—7 in deep and 6 in in diameter—which were soaked to saturation twice daily for 3 days (d). Twenty seeds were then sown on the surface of the soil in each pot. All pots were again soaked to insure soil moisture was near saturation before watering treatments were begun. A total of 150 pots were prepared.

Experimental design and treatments.—The study consisted of two experiments: In experiment A, pots received 0.0, 0.5, 1.0, 1.5, or 2.0 in of water at the beginning of each month. In experiment B, the same amounts of water were uniformly distributed throughout the month in applications of 0.25 in. Both experiments were randomized block designs, with water at five levels replicated 15 times.

Greenhouse environment.—Environment in the greenhouse at Fort Collins approximated field conditions during the growing season on the Fraser Experimental Forest. Air temperatures were set for a maximum of 70°F during the day and a minimum of 40°F at night. The photoperiod was 16 hours (h) of natural and artificial light. The transition period of temperature changes coincided with light changes. Relative humidity varied from 20% to 30% during the day to 70% to 80% at night. Light intensities inside the greenhouse varied from 3,000 footcandles (fc) on cloudy days to about 5,000 fc on clear days.

Measurements and analyses.—Number of germinating seeds, number of surviving seedlings, and apparent cause of mortality were recorded twice weekly. At the end of 22 weeks, the soil was carefully washed from the roots of all live seedlings, and the top height and root length were measured to the nearest millimeter. The tissue was then ovendried for 24 h at 100°C and weighed to the closest 0.1 mg.

Germination and survival were expressed as percentages of the number of seeds sown per pot; top height, root length, and total dry weight were pot means. Differences due to treatment were tested for significance at $\alpha = 0.05$ by analyses of variance and multiple comparison tests.

Results

Germination.—Average germination for experiment A (watered once a month) ranged from 39.6% for the 0.0-in treatment to 81.0% for the 1.5-in treatment (fig. 1). In experiment B, germination increased linearly from 23.3%, with no water after sowing, to 90.7% at 2.0 in/mo (fig. 1).

Germination rates.—Initial rates of germination were similar in both experiments (fig. 2). In experiment A, however, additional seedlings germinated following each monthly watering. In contrast, most of the seedlings in experiment B had germinated by the seventh week after sowing. Germination continued over a longer period at higher water levels (fig. 2).

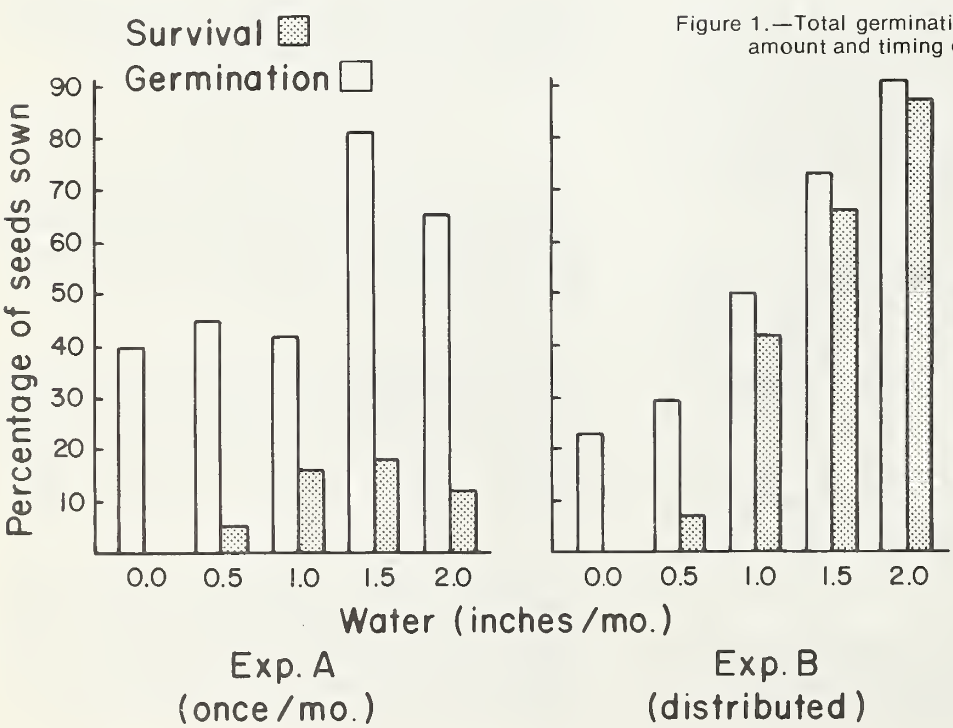

Figure 1.—Total germination and survival in relation to amount and timing of watering treatments.

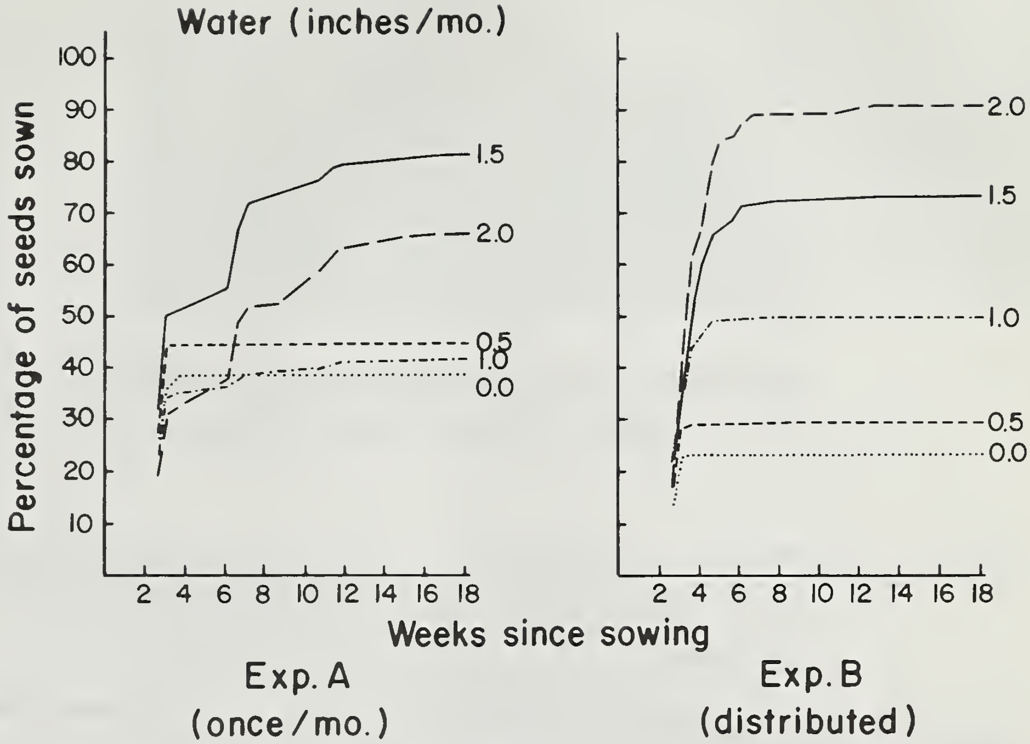

Figure 2.—Rate and pattern of germination in relation to amount and timing of watering treatments.

Survival.—Seedling survival in experiment B was considerably greater than in experiment A at the higher watering levels (fig. 1). Less than 20% of the seeds sown survived at the three highest water levels in experiment A, while 42%, 66%, and 87% of the seeds sown survived in experiment B.

Causes of mortality.—In this study, 99% of the mortality was attributed to three causes—drought, failure to establish, and damping off. Drought was the primary cause of mortality at all watering levels in experiment A, and in all but the 2.0-in treatment in experiment B. In both studies, seedlings of all ages died of drought, but losses were heaviest during the first 3 weeks after germination. However, mortality of seedlings in both studies receiving 0.5 in/mo of water increased again between 13 and 15 weeks after germination. Mortality rates then leveled off, and few seedlings died during the remainder of the study.

Failure to establish, or the inability of a seedling to initiate active growth after germination, was the second most common cause of mortality (25% of the mortality in experiment A, and 20% in experiment B). All mortality from failure to establish occurred within 24 d after germination.

Damping off was not a serious problem in either study; it accounted for 1.2% of the mortality in experiment A and 5.4% in experiment B. All but one of these seedlings died within 7 d after germination.

Seedling growth.—To compare the effect of amount of water on seedling growth, average dry weight, root length, shoot height, and root/shoot ratios were analyzed for the 1.0-, 1.5-, and 2.0-in treatments in both studies. Seedling growth data from the 0.5-in levels were not included in the analysis because of poor survival, but have been retained in table 1 for comparison.

Seedlings in both studies produced significantly more dry weight at the 1.5-in watering level than at the 1.0-in level. In experiment A, seedlings in the 1.5-in treatment were also significantly heavier than those in the 2.0-in treatment (table 1). Although experiments A and B were not compared statistically, distribution of water did not appear to affect the dry weight production of seedlings at levels above 1.0 in/mo of water.

Root lengths were not significantly different among watering levels when seedlings were watered once a month. However, when water was distributed throughout the month, seedlings in the 1.5-in treatment had significantly longer roots than those in the 1.0-in treatment (table 1). Roots of seedlings watered once a month had longer roots than those watered throughout the month.

Shoots of seedlings in experiment B were significantly shorter at the 1.0-in watering level than at the 1.5- and 2.0-in levels. Heights were not significantly different at any watering level for experiment A seed-

Table 1.--Average growth of greenhouse-grown lodgepole pine seedlings watered once a month, experiment A, and at predetermined intervals during the month, experiment B (Means for each variable with common subscripts are statistically homogeneous at $\alpha=0.05$; 0.5-inch treatment not included in analysis)

Monthly water treatment (Inches)	Dry weight		Seedling height		Root length		Root/shoot ratio	
	A	B	A	B	A	B	A	B
	mg		*mm*		*mm*			
0.5	507.4	724.5	33.4	36.2	239.5	215.0	7.30	5.99
1.0	605.7a	631.4a	37.1	38.5a	238.8	208.4a	6.43	5.45
1.5	766.6b	838.4b	39.8	42.6b	234.4	229.3b	5.96	5.41
2.0	623.2a	757.4b	37.3	43.1b	237.1	221.2ab	6.09	5.16

lings (table 1). Root/shoot ratios were not significantly different in either experiment.

Conclusions

- Mean germination is not drastically affected by the timing of water application (once a month vs 0.25-in increments equally distributed through the month), but is dependent upon the total amount of water received. However, timing of water application does affect the rate and pattern of germination.
- Survival of seedlings will be poor, regardless of the amount of water received, if it is applied only once a month. If water is applied regularly at short intervals, survival increases with increasing amounts of water per month.
- The most critical period for seedling survival appears to be the first 3 weeks after germination. Most seedlings that survived the first 3 weeks and received at least 1.0 in of water distributed through the month lived throughout the studies reported here.
- Dry weight and shoot height increase somewhat with increases in the amount of water received. The effect of water on roots remains unclear.

These studies have been concerned only with precipitation, and do not reflect the many other environmental factors that affect regeneration. In addition, the environment maintained in the greenhouse was more favorable to seedling establishment and growth than most natural conditions. Nevertheless, the results obtained substantiate earlier field observation of Lotan (1964) and Ronco (1967), who suggested that ideal precipitation conditions for germination and survival of lodgepole pine would be at least an inch of rainfall per month, received in small showers throughout the growing season.

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